16th Patras Workshop on Axions, WIMPs and WISPs

CYGNO- A 3D OPTICAL READOUT TPC FOR DIRECTIONAL DARK MATTER SEARCHES

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Outline

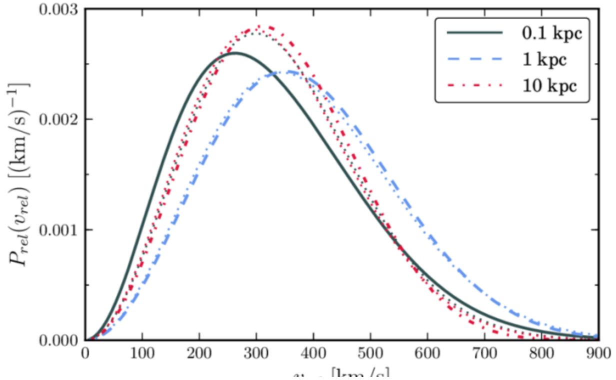
- Dark Matter and WIMPs
- How can we explore Dark Matter?
- Importance of Directionality in Dark Matter Searches
- Time Projection Chambers with Optical Readout
- CYGNO Roadmap
- MANGO
- LEMOn
- LIME
- CYGNO 1m3
- What can we do?
- CYGNUS Collaboration

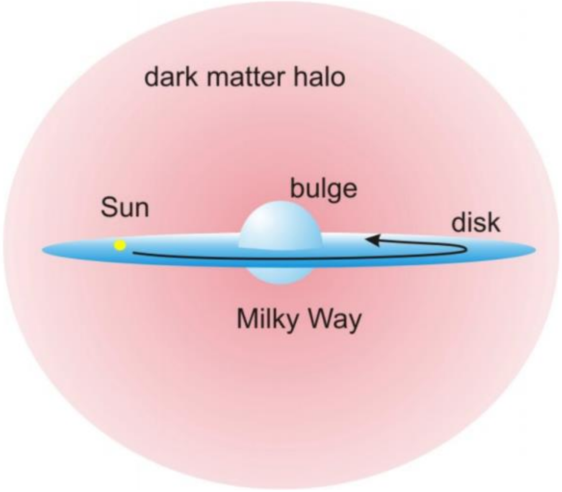
Dark Matter and WIMPs

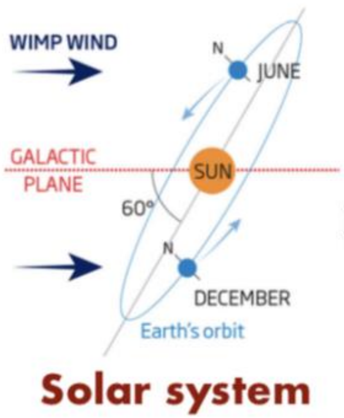
- One of possible constituents of Dark Matter are the Weakly Interacting Massive Particles: neutral particles with a very low interaction probability with ordinary matter;

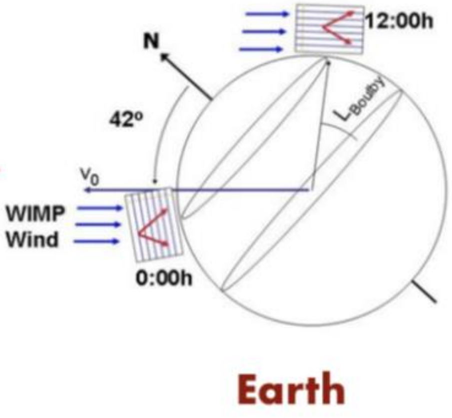
- Our Milky Way, like most galaxies, is surrounded by an approximately spherical halo of WIMPs. The Sun and the planets move through this halo towards CYGNUS constellation intercepting a WIMP wind originating from it.

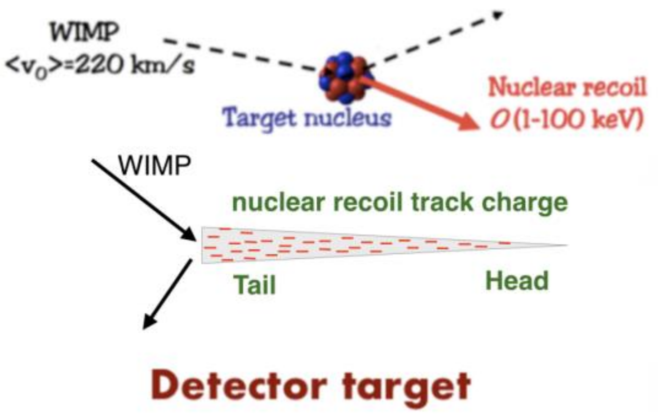
- Events caused by Dark Matter interactions have a preferential direction in space because of the Earth's motion with respect to the Dark Matter Halo





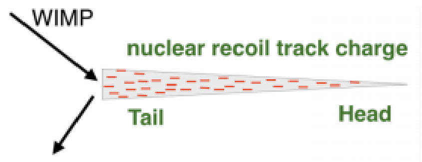






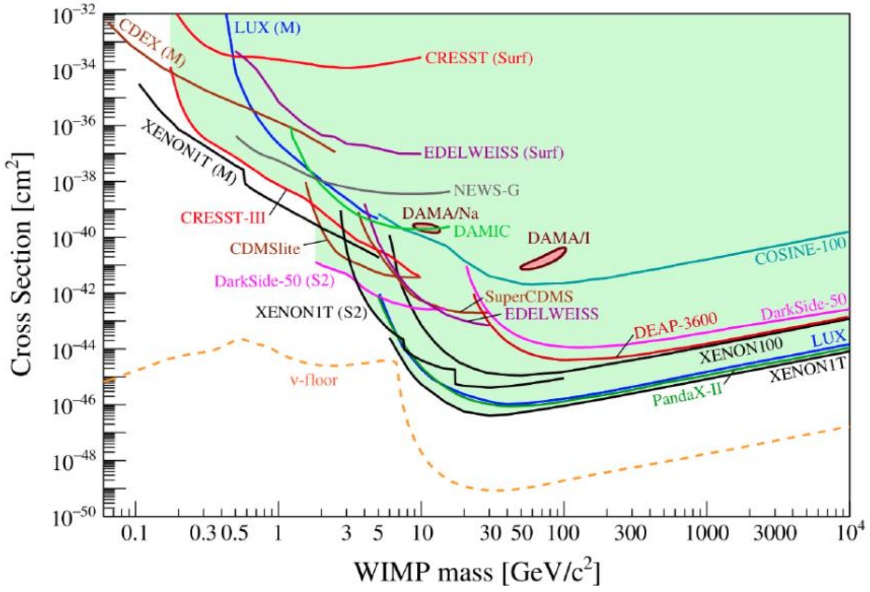
How can we explore Dark Matter?

- One possibility is trying to detect the products of its interactions with ordinary matter, through charged particles that we know how to detect;



- In order to maximize the fraction of transferred energy it is then crucial to have target of almost same mass

Element	Max E transferred by a 1 GeV WIMP	Min WIMP mass with 1 keV threshold
H	2.00 keV	0.5 GeV
He	1.30 keV	0.9 GeV
C	0.57 keV	1.4 GeV
F	0.38 keV	1.7 GeV
Na	0.32 keV	1.8 GeV
Si	0.27 keV	2.0 GeV
Ar	0.20 keV	2.4 GeV
Xe	0.06 keV	4.2 GeV



- Large regions of high masses spectrum already explored without any confirmed evidence of WIMP
- Focus shift towards lower masses (below 10 GeV)
- Lower mass elements provide the best candidate targets (He and H)
- Enables the identification of the topological signature of different events (e.g. ER and NR).

Importance of Directionality in Dark Matter Searches

Energy information

- Falling exponential with no peculiar features

Temporal information

- A few percent (%) annual modulation

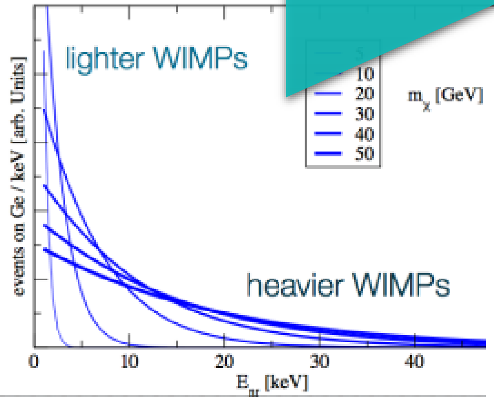
Directional information

- Allows unequivocally the identification of the event

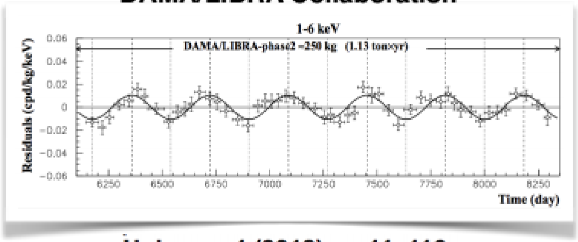
What can we explore?

- Capability to reject isotropy
- Capability to discriminate neutrinos from WIMPs
- Capability to probe DM nature

How can we do it?



DAMA/LIBRA Collaboration



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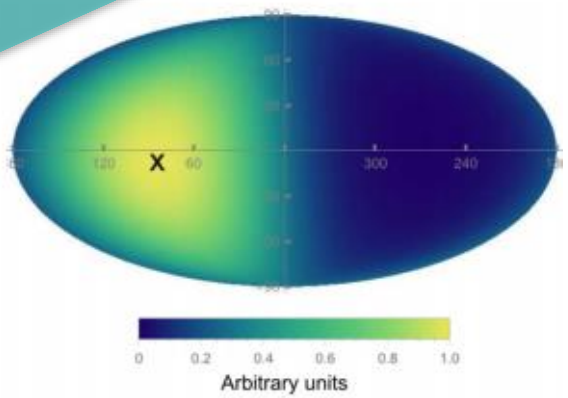
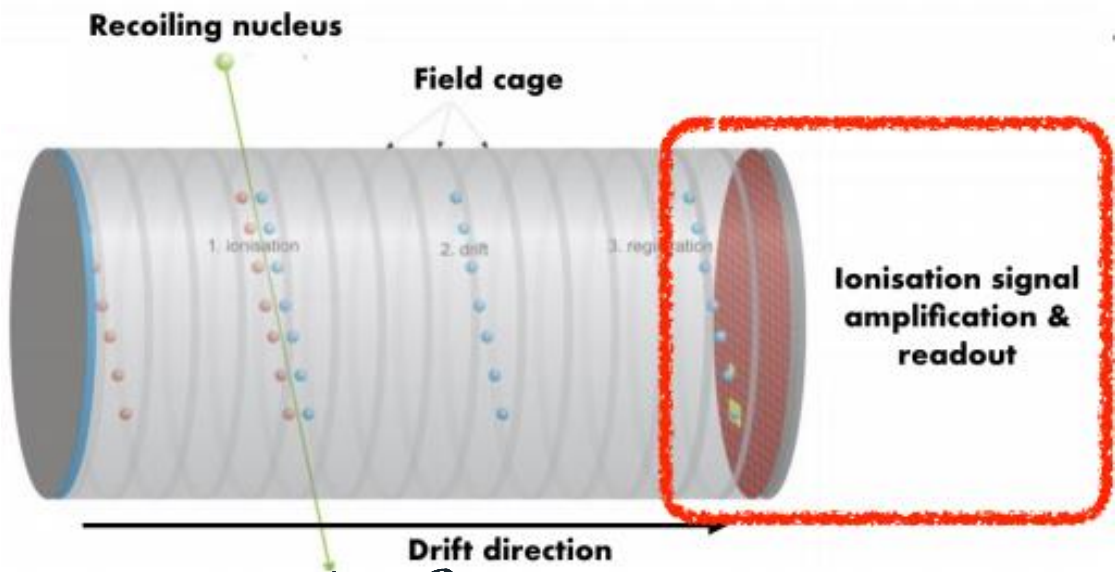
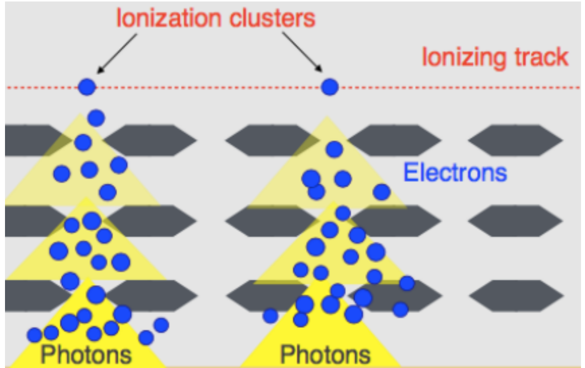


TPC with Optical Readout



What is our idea?

- Readout the light produced during the charge avalanche



What can we get?

- 3D tracking (position and direction)
- Particle ID (dE/dx)
- Axial directionality
- Head/tail
- Background rejection
- 3D fiducialization

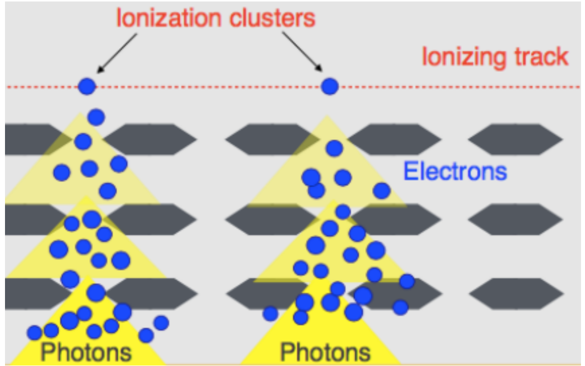
Different technologies can be used to readout the signal.

Enabling to reduce the number of channel numbers thus the DAQ complexity

TPC with Optical Readout

Why using optical readout?

- Readout the light produced during the charge avalanche



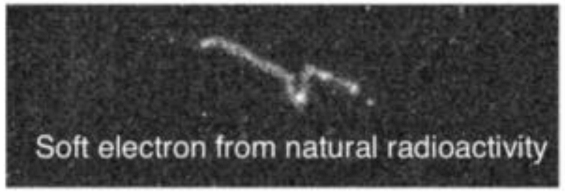
Optical sensors provide high sensitivity and granularity, with a fast response with very low noise level.

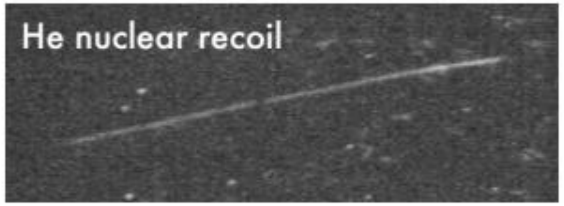
Optocoupling enables to keep sensor out of sensitive volume (HV independent and lower gas contamination).

Suitable lens allow the development of large sensitive area solutions.

sCMOS:

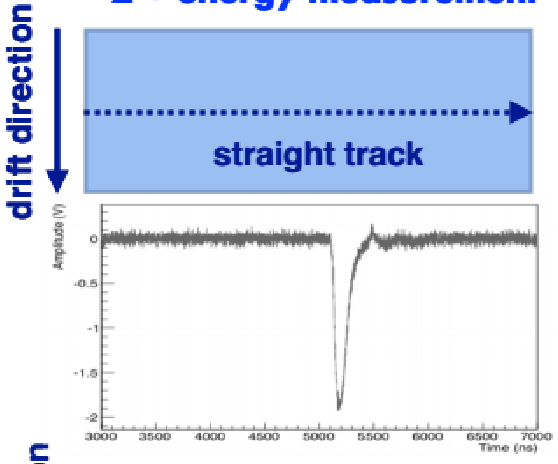
high granularity
X-Y + energy measurements

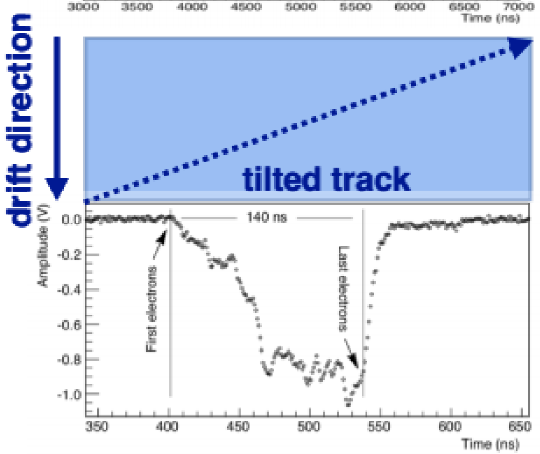




PMT:

integrated
Z + energy measurement





Complete analysis of the emission spectra

CYGNO Experiment

CYGNO Roadmap

Phase 0: R&D

Phase 1: O(1) m3 Demonstrator

ORANGE

@ROMA1

- 1cm drift

2015-2016

LEMOn

@LNF

- 3D printing
- 20 cm drift

2017-2018

MANGO

@LNF/LNGS

- variable drift distance
- performance testing

2019-2021

LIME

@LNF/LNGS

- 50 cm drift
- underground tests
- shielding
- data taking

2021-2022

Construction & Test

@LNF/LNGS

- background
- material tests
- gas purification
- scalability

2022-2023

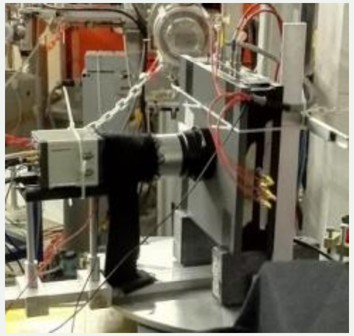
Installation & commissioning

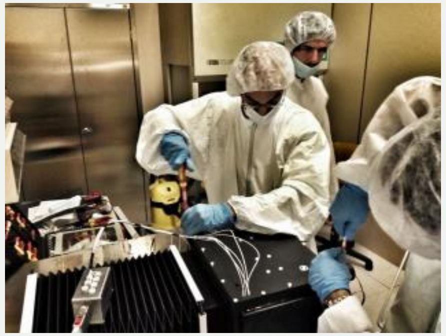
@LNGS

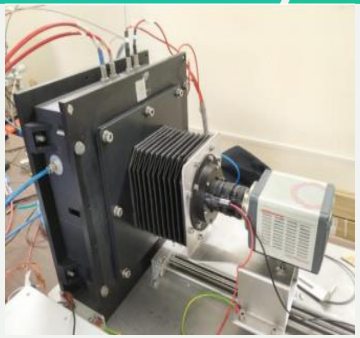
- installation and data taking with O(1) m3 detector

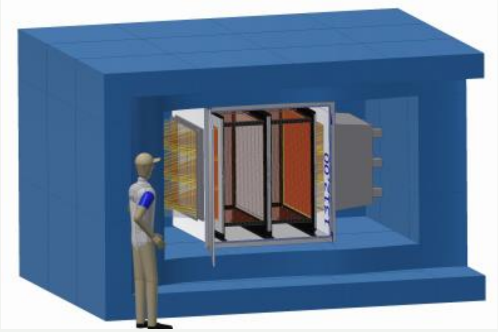
2023

CYGNUS 30-100 m3

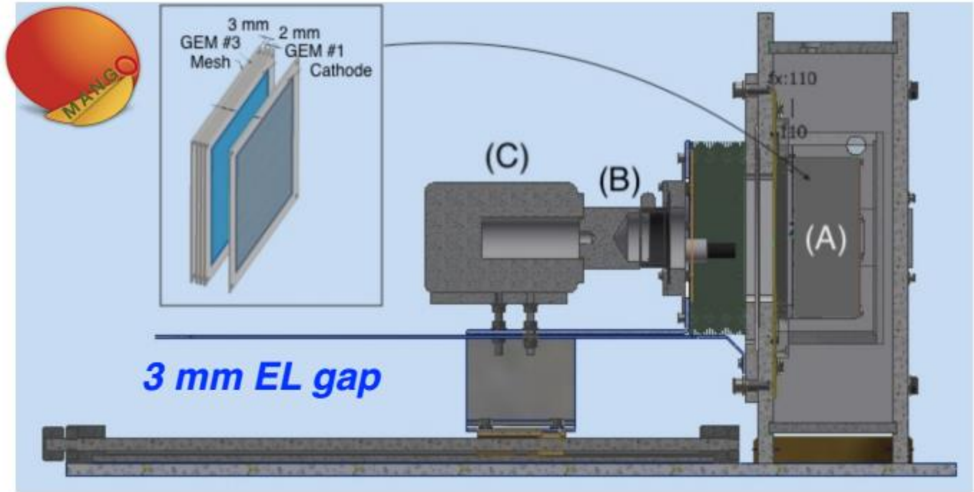


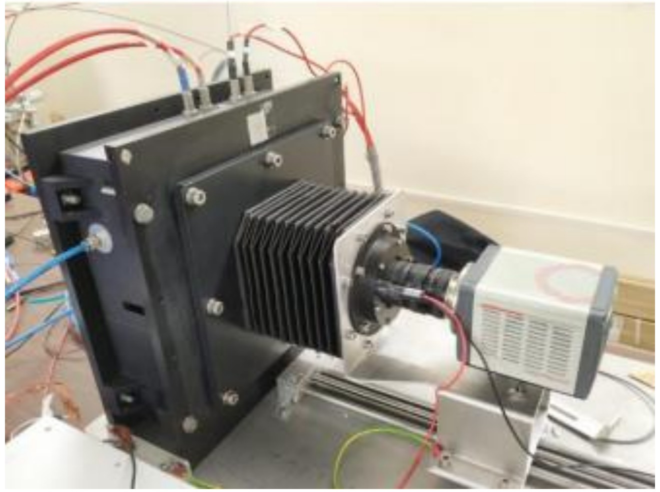


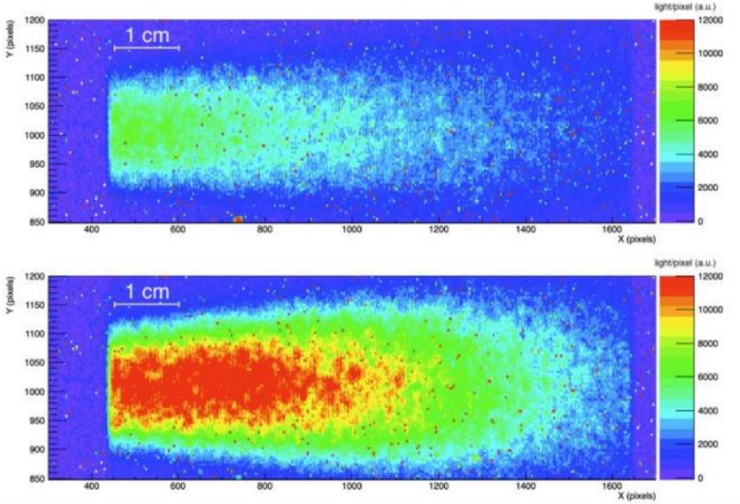


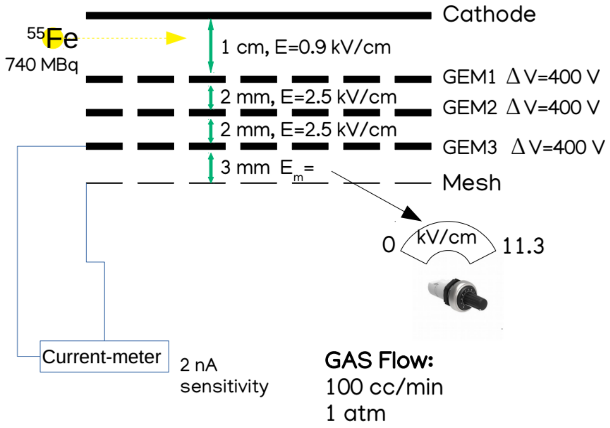


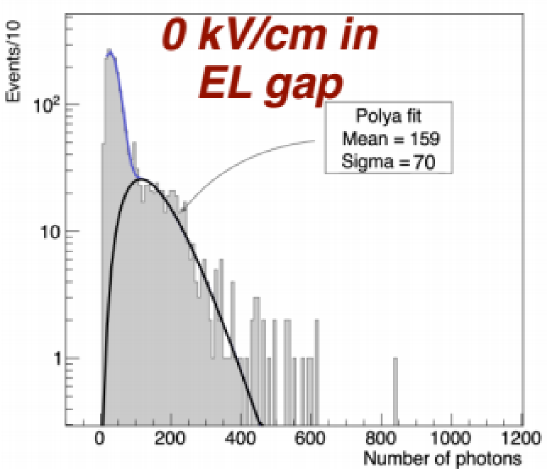
Electroluminescence in
MANGO

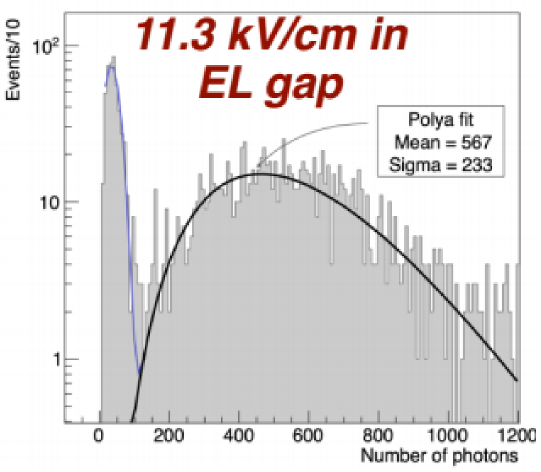


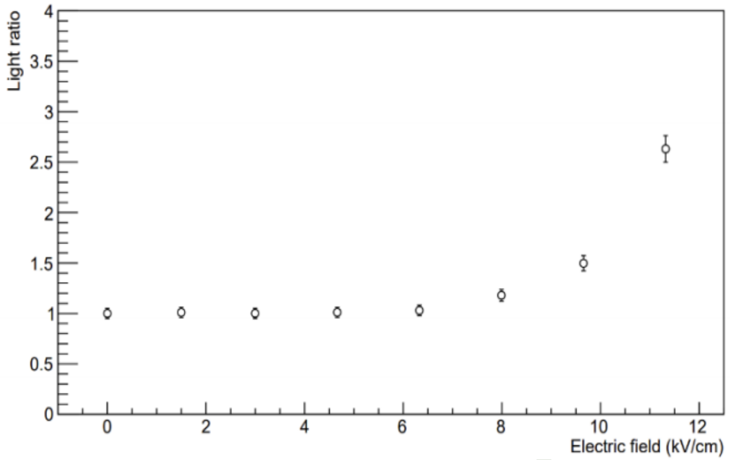










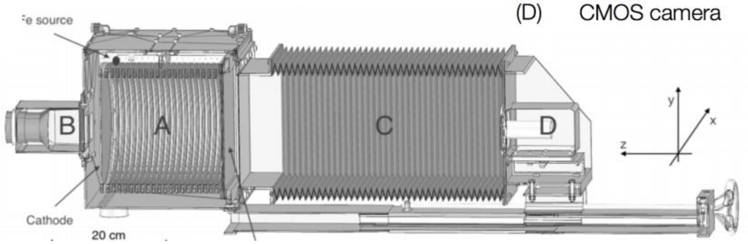


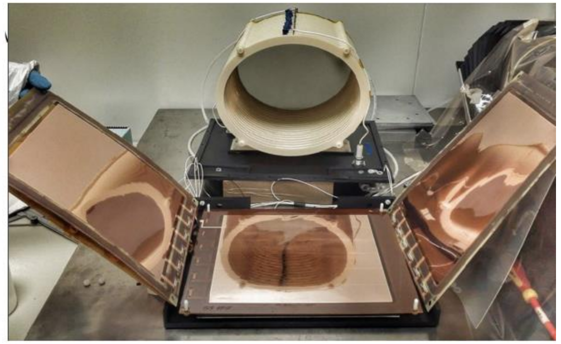
First observation of EL in He-CF4 mixture

Performance assessment with ^{55}Fe

1 sCMOS + 1 PMT
20 x 24 cm² readout area
20 cm drift
7 L active volume

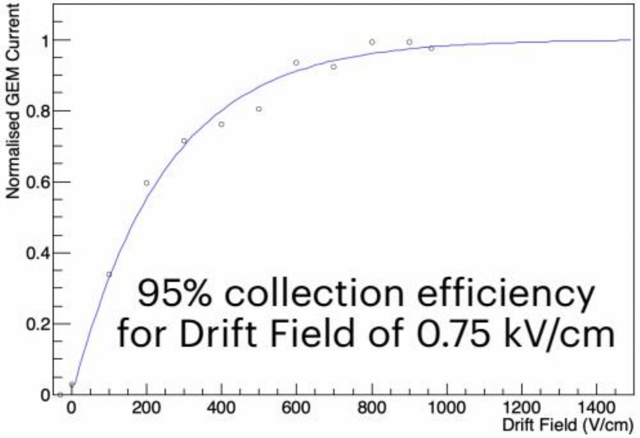
(A) Field Cage
(B) PMT
(C) Adaptable bellow
(D) CMOS camera

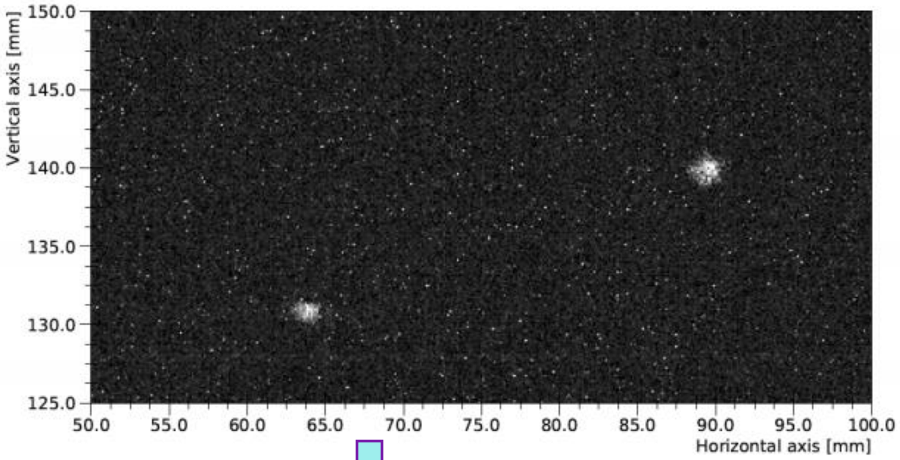


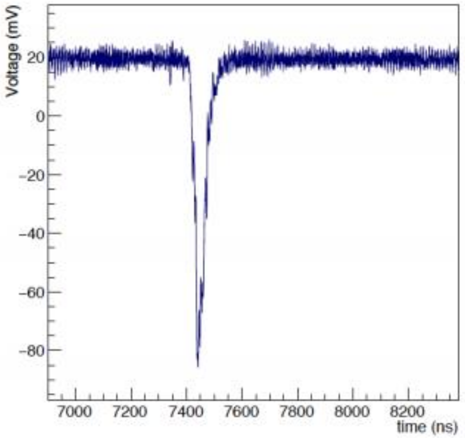


Energy resolution of **15%** a **5.9 keV** from both sCMOS and PMT

Diffusion can be **explored** to **evaluate** the **Z position** with an average **resolution** of **15%**.

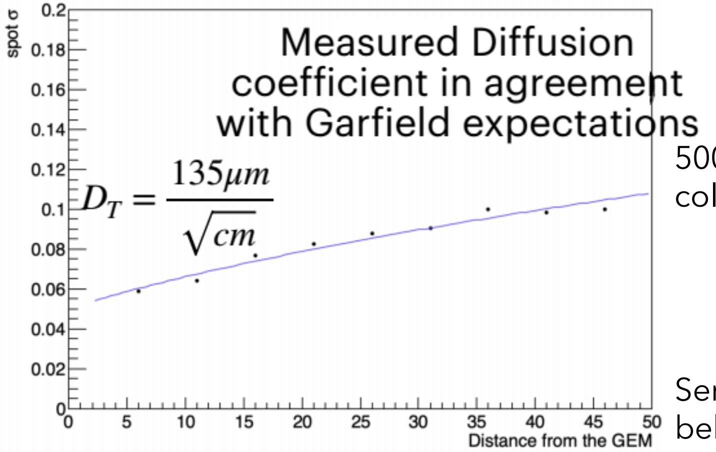






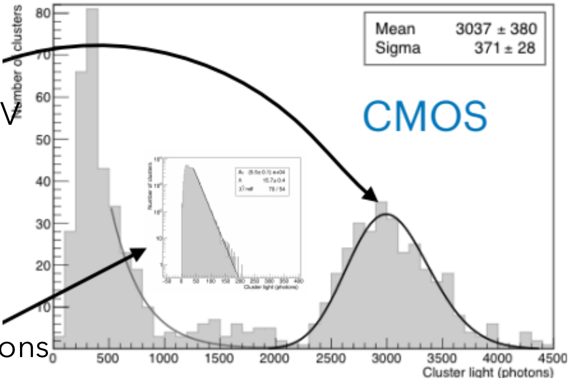
Transverse light profile and PMT signal waveform are expected to become smaller and larger.

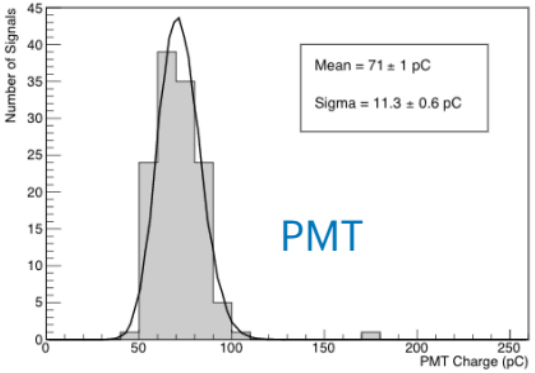
Z position



500 photons collected per keV

Sensor noise below 200 photons (I.e. 400 eV)





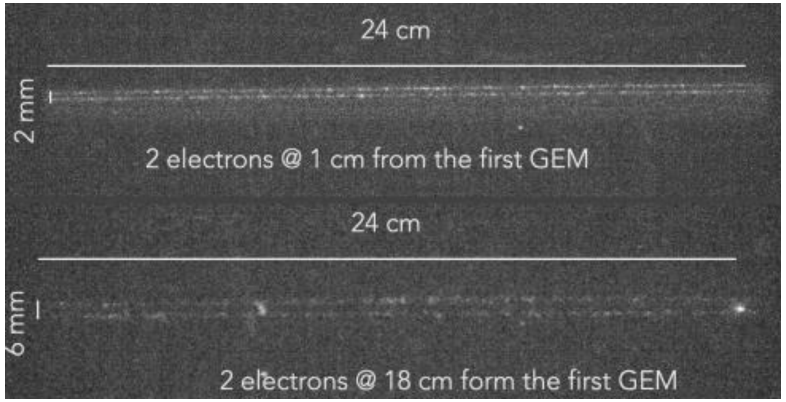
Since the width (S) increases and the amplitude (A) decreases with Z, their ratio increases.

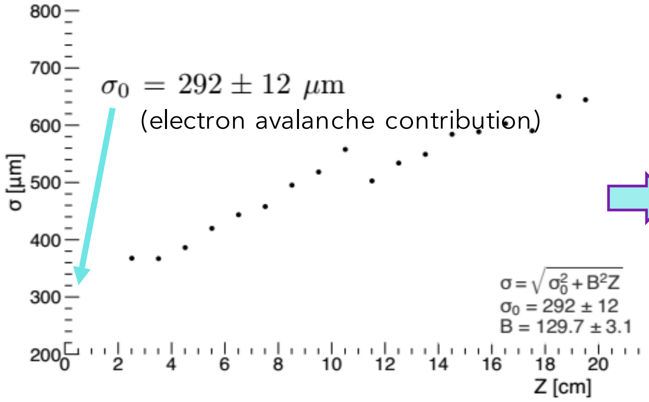
CYGNO Experiment

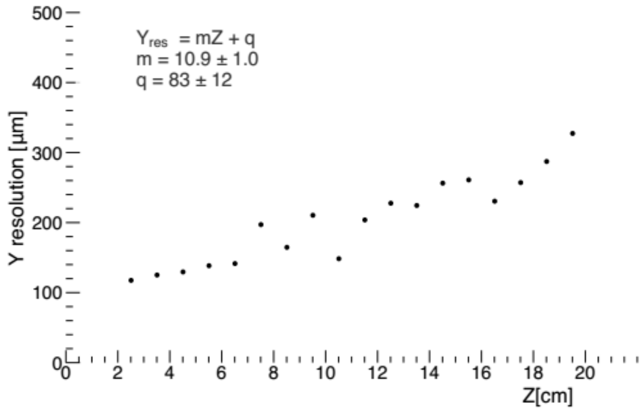
LEMOn

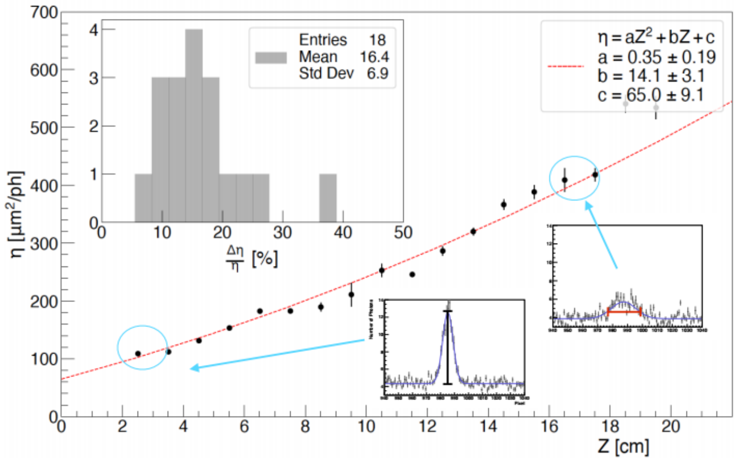
Performance assessment with 450 MeV electrons

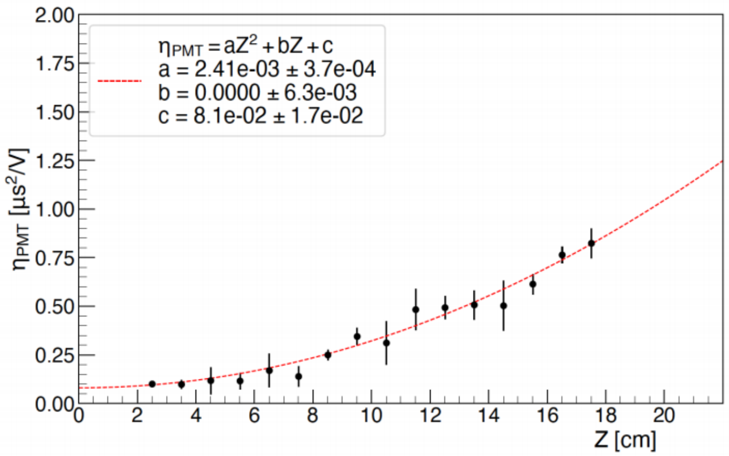
Diffusion can be **explored** to **evaluate** the **Z position** with an average **resolution** of **15%**.





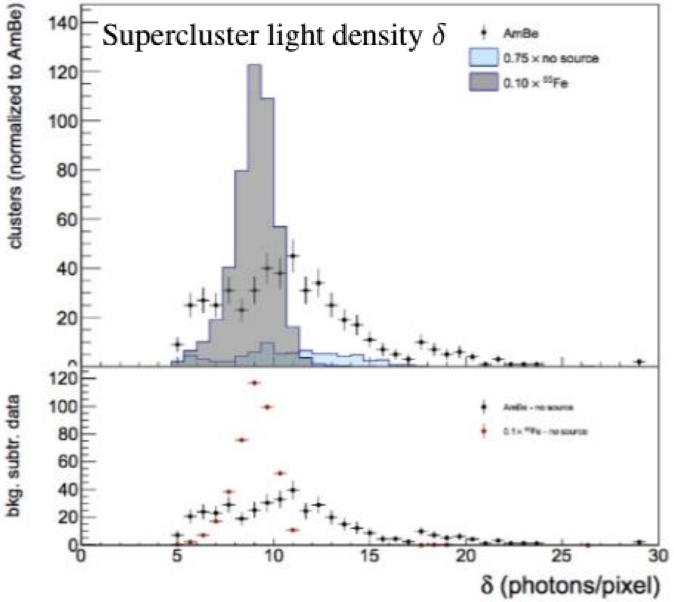


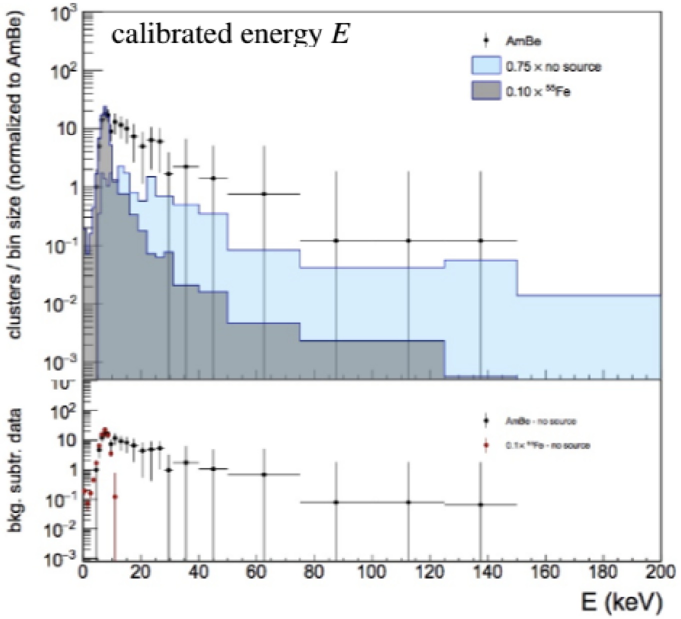


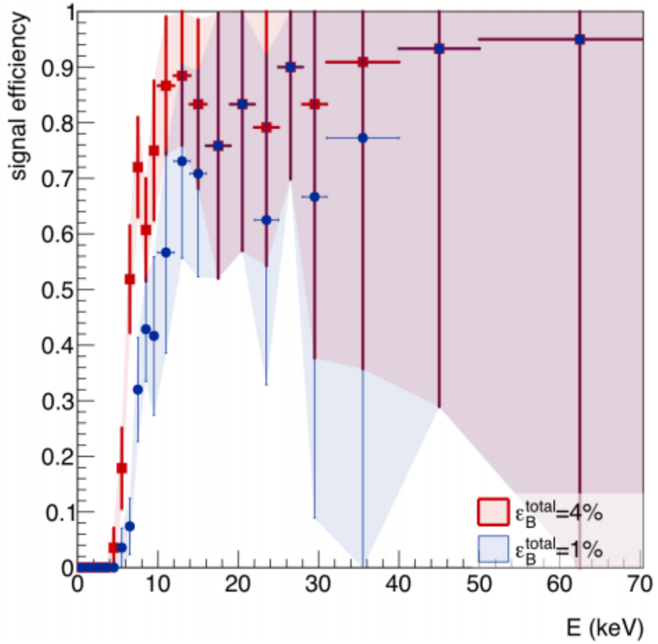


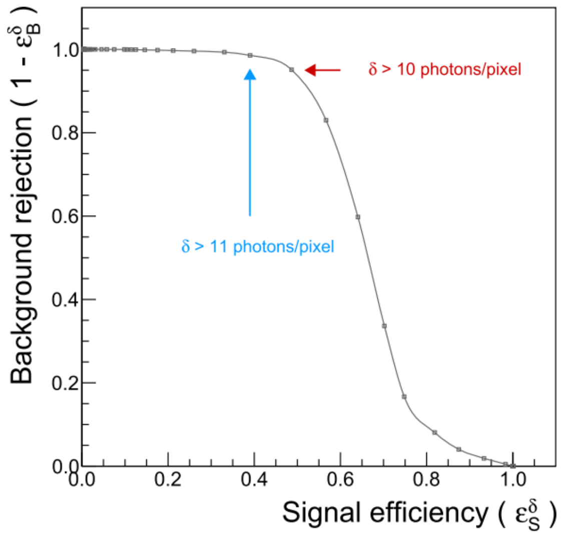
CYGNO Experiment LEMOn

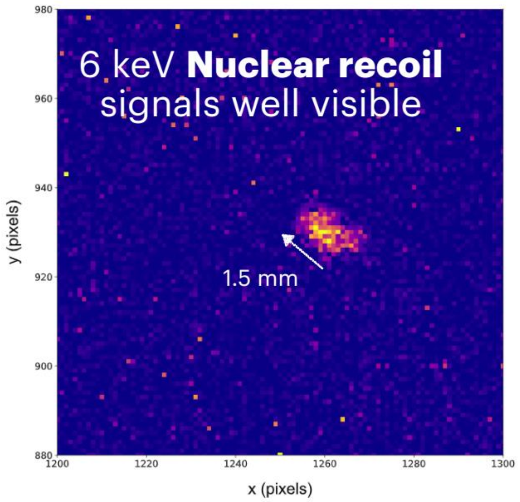
Performance assessment – Capability of identifying low-energy NR and discrimination capability (NR/ER)











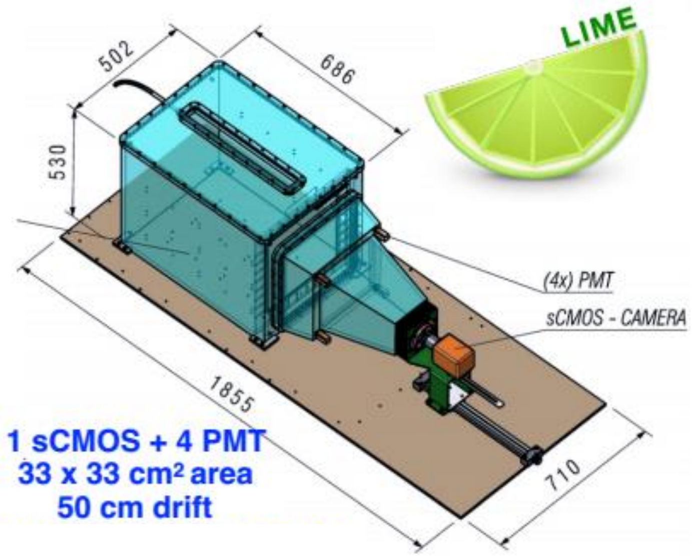
working point	Signal efficiency			Background efficiency		
	ε_S^{presel}	ε_S^{δ}	ε_S^{total}	ε_B^{presel}	ε_B^{δ}	ε_B^{total}
WP_{50}	0.98	0.51	0.50	0.70	0.050	0.035
WP_{40}	0.98	0.41	0.40	0.70	0.012	0.008

Table 1. Signal (nuclear-recoil-induced by AmBe radioactive source) and background (photoelectron recoils of x-rays with $E = 5.9$ keV from ^{55}Fe radioactive source) efficiency for two different selections on δ.

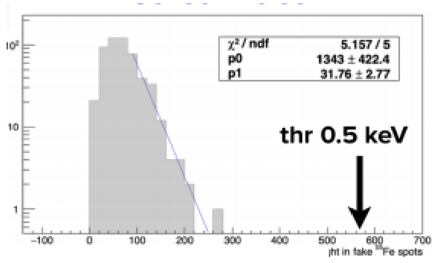
A sizeable efficiency in the range 5-10 keV was measured while more than 95% (99%) 55Fe photons were rejected.

CYGNO Experiment

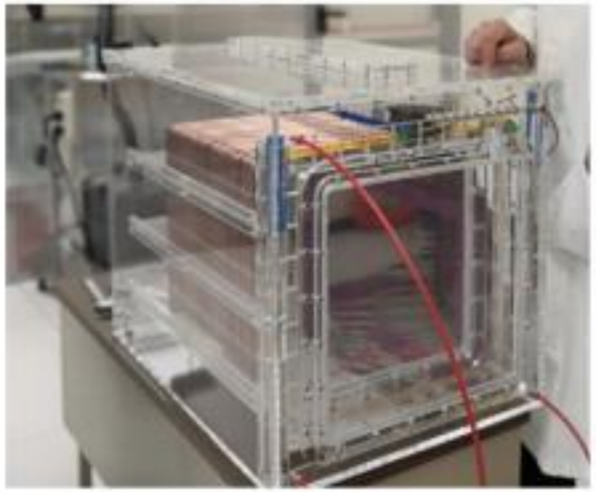
LIME

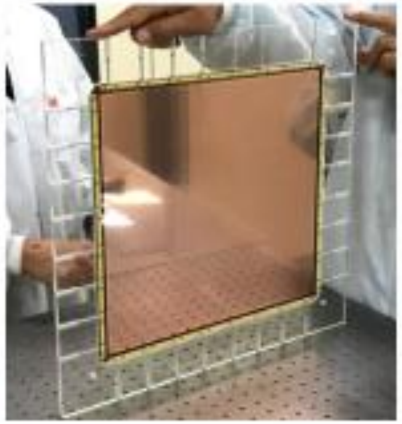


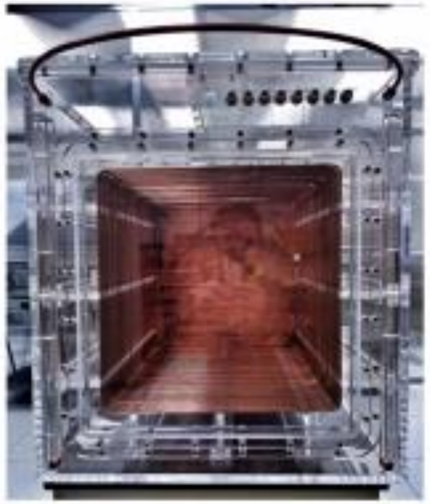
ORCA-Fusion

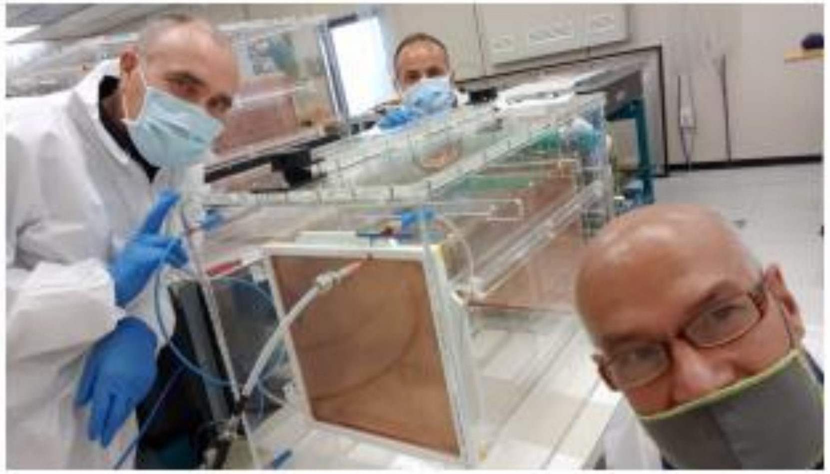


Large sensitivity
Low noise









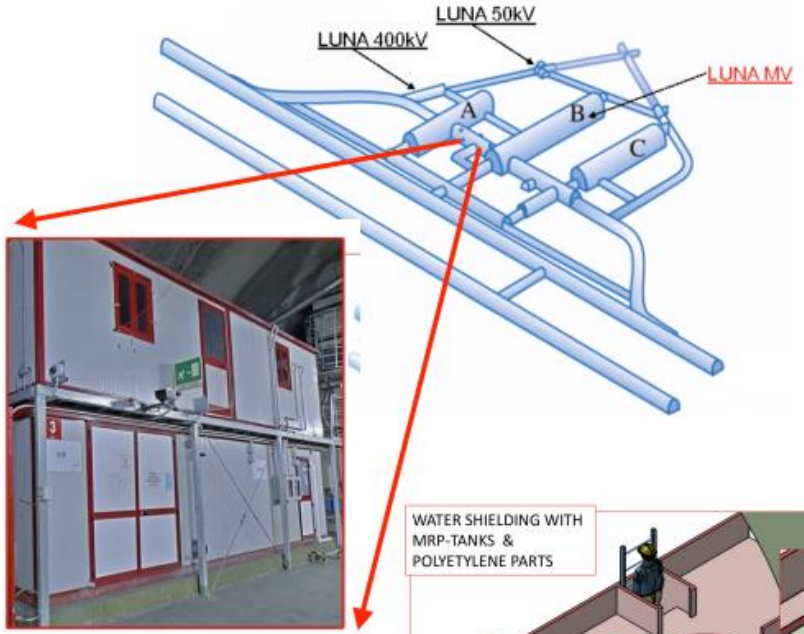
LIME Underground @ LNGS

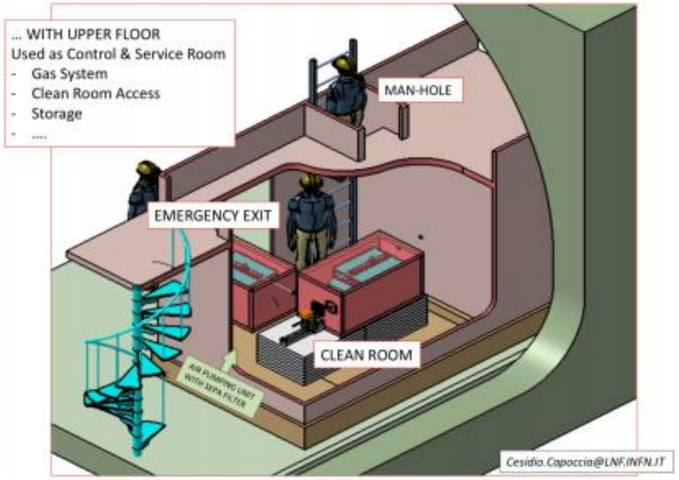
LIME is expected to be installed underground at LNGS (3600 m.w.e.) by fall 2021.

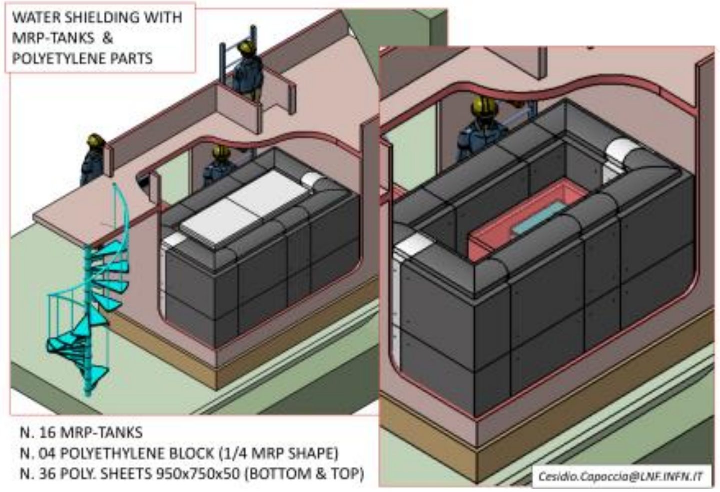
LIME goals:

- Measure environmental neutron flux

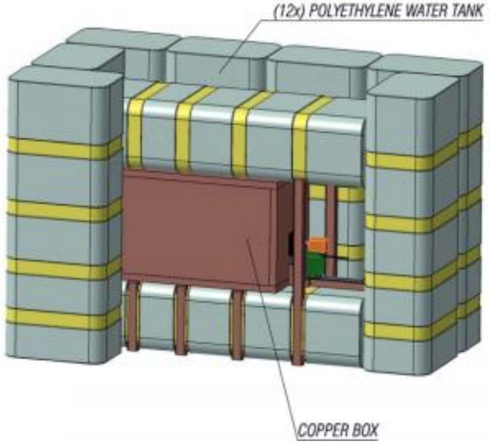
- Measure internal backgrounds towards O (1) m3 detector development







Neutron Shielding (50 cm water)



Gamma Shielding (10 cm Cu)

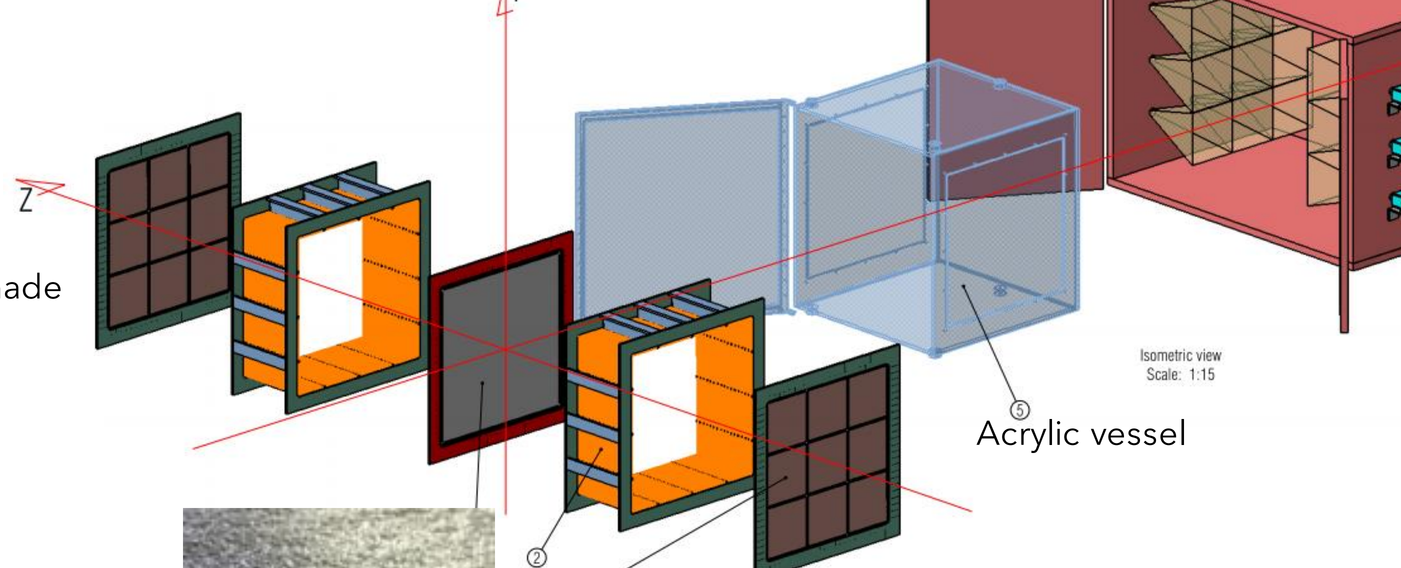
CYGNO Experiment

Preliminary

CYGNO O(1)m3

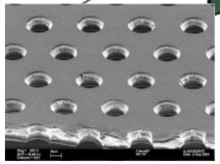
ROMA TRE UNIVERSITÀ DEGLI STUDI · The University Of Sheffield. · SAPIENZA UNIVERSITÀ DI ROMA · ufjf UNIVERSIDADE FEDERAL DE JUIZ DE FORA · 1290 UNIVERSIDADE D COIMBRA · GSSI GRAN SASSO SCIENCE INSTITUTE SCHOOL OF ADVANCED STUDIES Scuola Universitaria Superiore · INFN Istituto Nazionale di Fisica Nucleare · CBPF Centro Brasileiro de Pesquisas Fisicas

- O(1) m3 of He-CF_4 (60-40) at atmospheric pressure and room temperature
- Modular detector – LIME-like modules
- Back-to-back TPC with 50 cm drift of 1 kV/cm



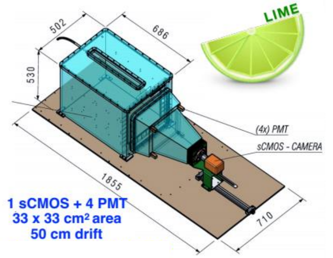
Amplification Stage made using a triple-GEM

Central cathode



GEM (~1x1 m2)

LIME-like modules



sCMOS sensor 65 cm away
Almost 10^8 readout pixels (165x165 um²)

Fast light detector (PMT or SiPM).

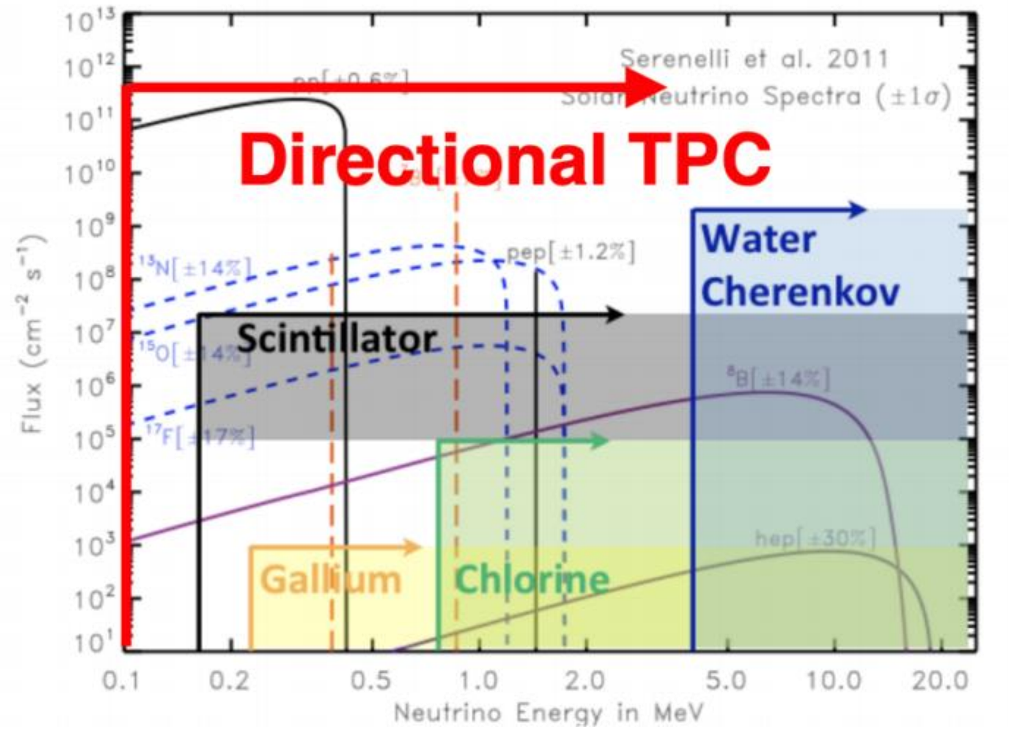
Radioactivity shielding:
- 5 cm thick copper box (and similar Faraday cage)
- 200 cm of water

What opportunities are there?

Neutrinos are seen as unwanted background but can also be interesting to explore.

➡ **Neutrino Spectroscopy**

Using a gaseous TPC we can study the neutrinos via electron scattering.



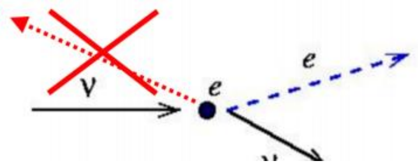
Here is the reason why...

- sub-millimetre tracking capability (Borexino is 12 cm)
- 10 keV directional threshold for electron recoils
- keV energy resolution
- low mass target

For 1 m³ of He:CF₄ 60:40 with 20 keV threshold

$$R = N_e \cdot \int_{E_{min}}^{E_{max}} w(E)\varphi_{ppI}(E)\sigma(E)dE \qquad R = 2.9 \cdot 10^{-8}\,\frac{events}{s \cdot m^3} = 0.9\,\frac{events}{y \cdot m^3}$$

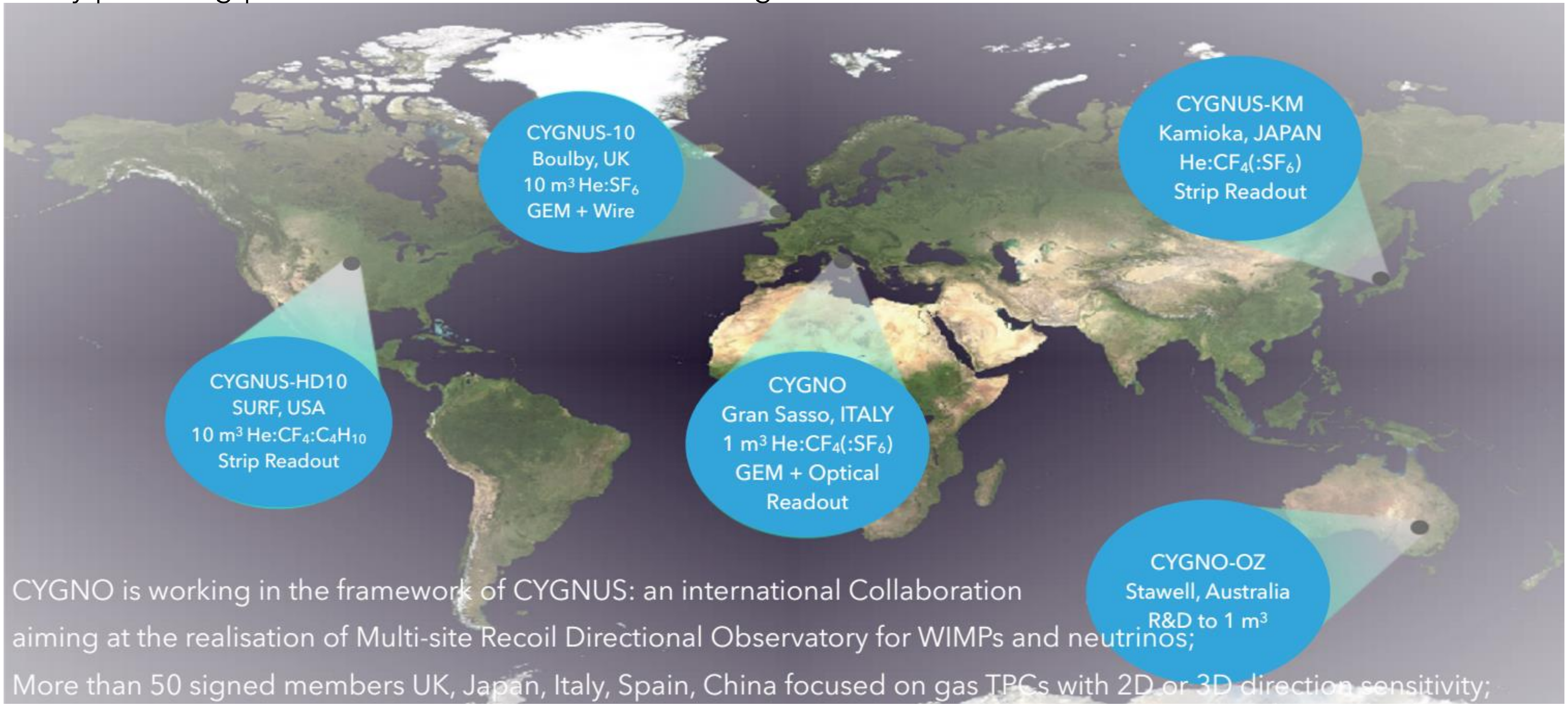
Given the Sun position, recoils in opposite direction are kinematically forbidden



Differently from WIMPs, background can be measured on sidebands data

CYGNUS Collaboration

CYGNO project is developing a GEM-based TPC optically readout for rare event studies
Very promising performance was found in the keV region



Thank you


FISICA
FISICO
MARCONI
CYGNUS 2019
10 - 12 July 2019
Seventh workshop on directional dark matter searches
Sapienza Università di Roma - Dipartimento di Fisica
Edificio Marconi - Aula Conversi
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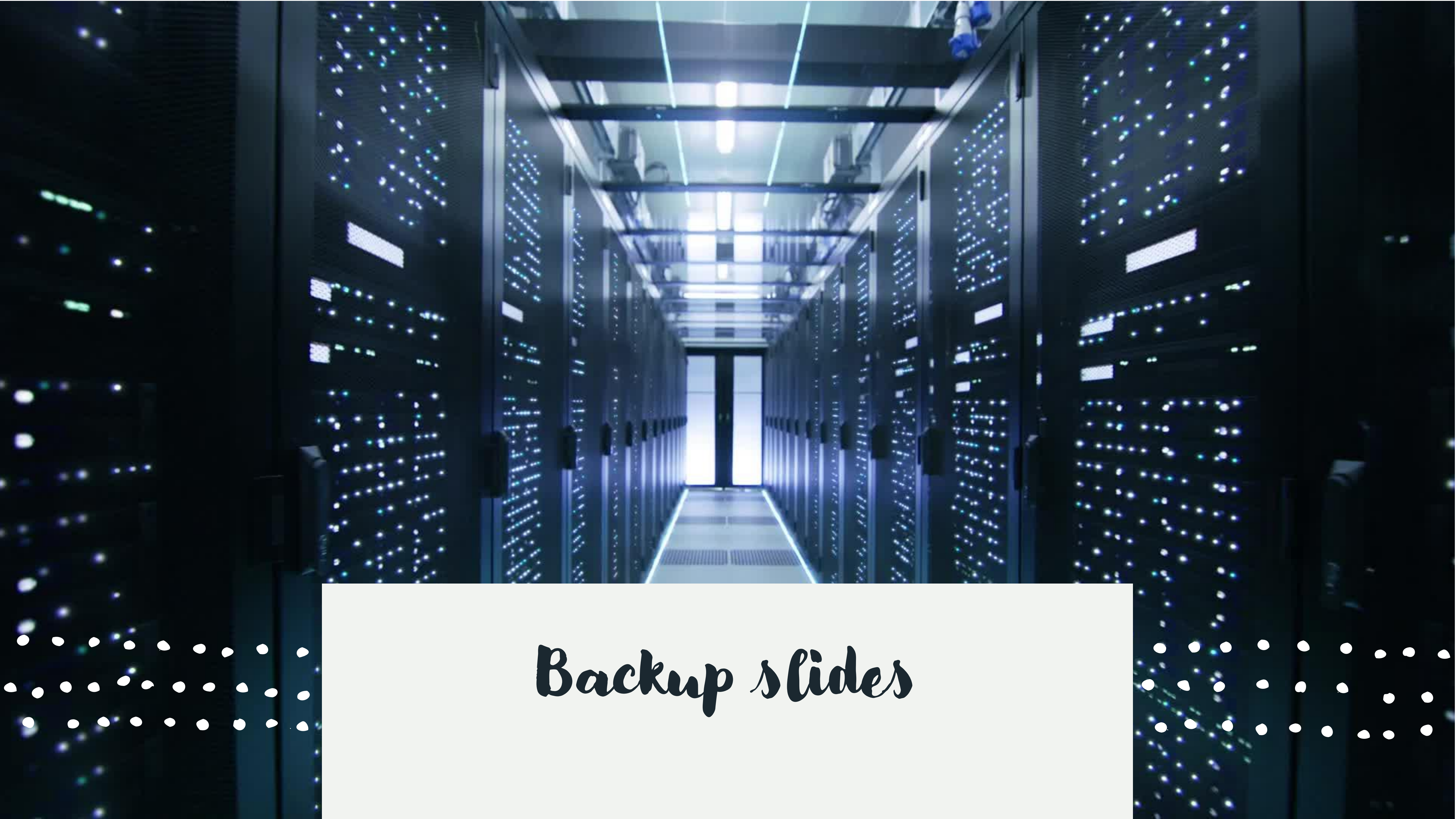

Backup slides

Why sCMOS and PMTs?

- High granularity
- Lower number of channels to readout large areas
- X-Y position and energy deposit measurements
- Fast response

PMT Hamamatsu R1635

1/3 noise w.r.t. CCDs
Market pulled
Single photon sensitivity
Decoupled from target gas
Large areas with proper optics